Information Management in a Tactical Mobile Wireless Communications Environment

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Outline of Presentation

- Challenges Posed by the Tactical Communications Environment
- Data Replication over Disadvantaged Tactical Communication Links (workshop summary)
- Role of Middleware in Systems Functioning over Mobile Wireless Networks (workshop summary)

Revolution in Battlefield Command and Control

‘Network-Centric Warfare’

- ‘An information-superiority enabled concept of operations that generates increased combat power by networking sensors, decision makers and shooters to achieve:
  - shared awareness
  - increased speed of command
  - higher tempo of operations
  - greater lethality
  - increased survivability
  - a degree of self-synchronization

D.S. Alberts, J.J. Garstka, F.P. Stein, ‘Network centric warfare: developing and leveraging information superiority’, CCRP Publication Series, 1999

"Giving bad commanders more information does not make them good. They just make bad decisions faster, or get so overwhelmed that they can't make any decision"

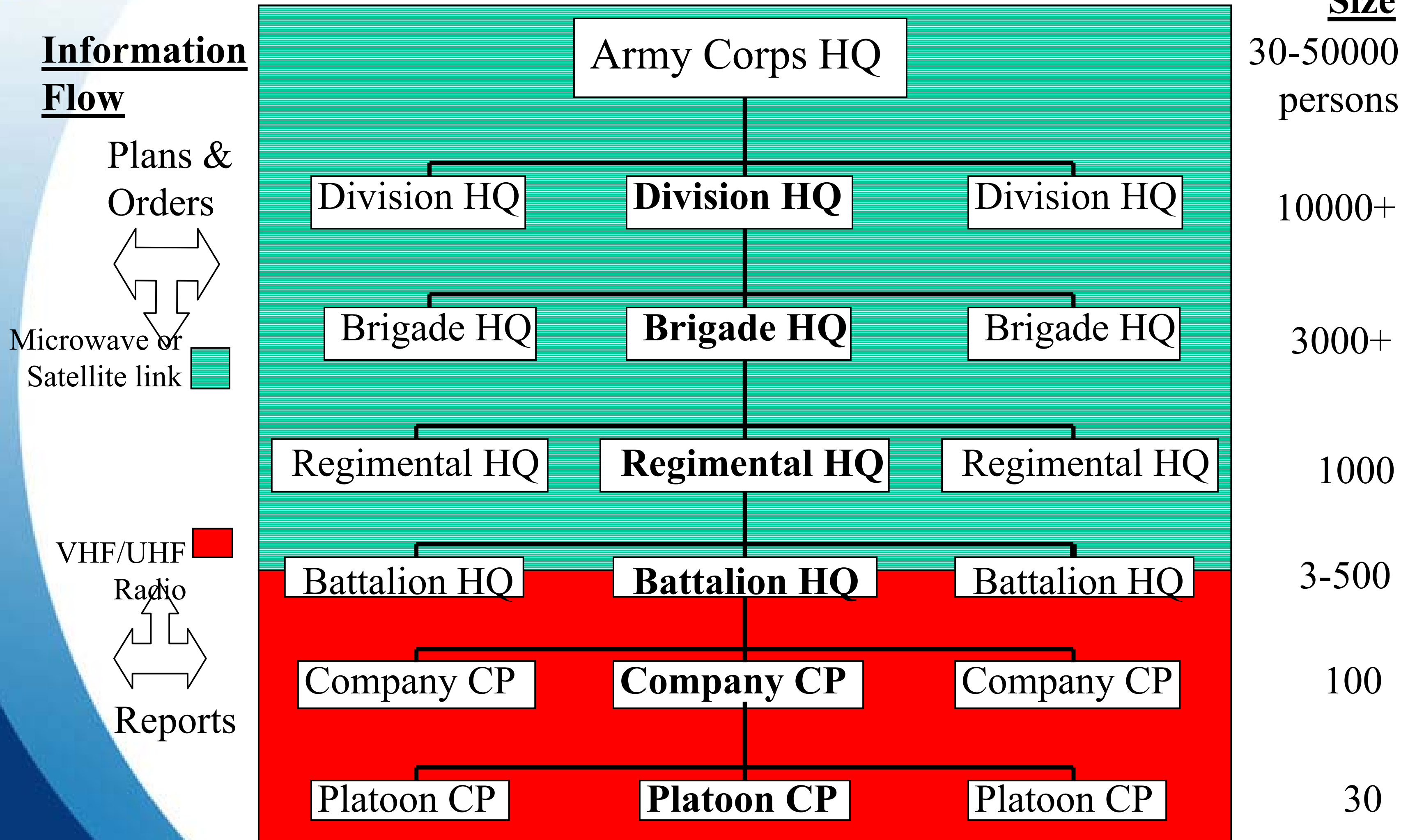
Revolution in Battlefield Command and Control

- Introduction of digital C2I systems
- Need to distribute digital data
  - quickly
  - widely
  - reliably

Army Command and Control Structure

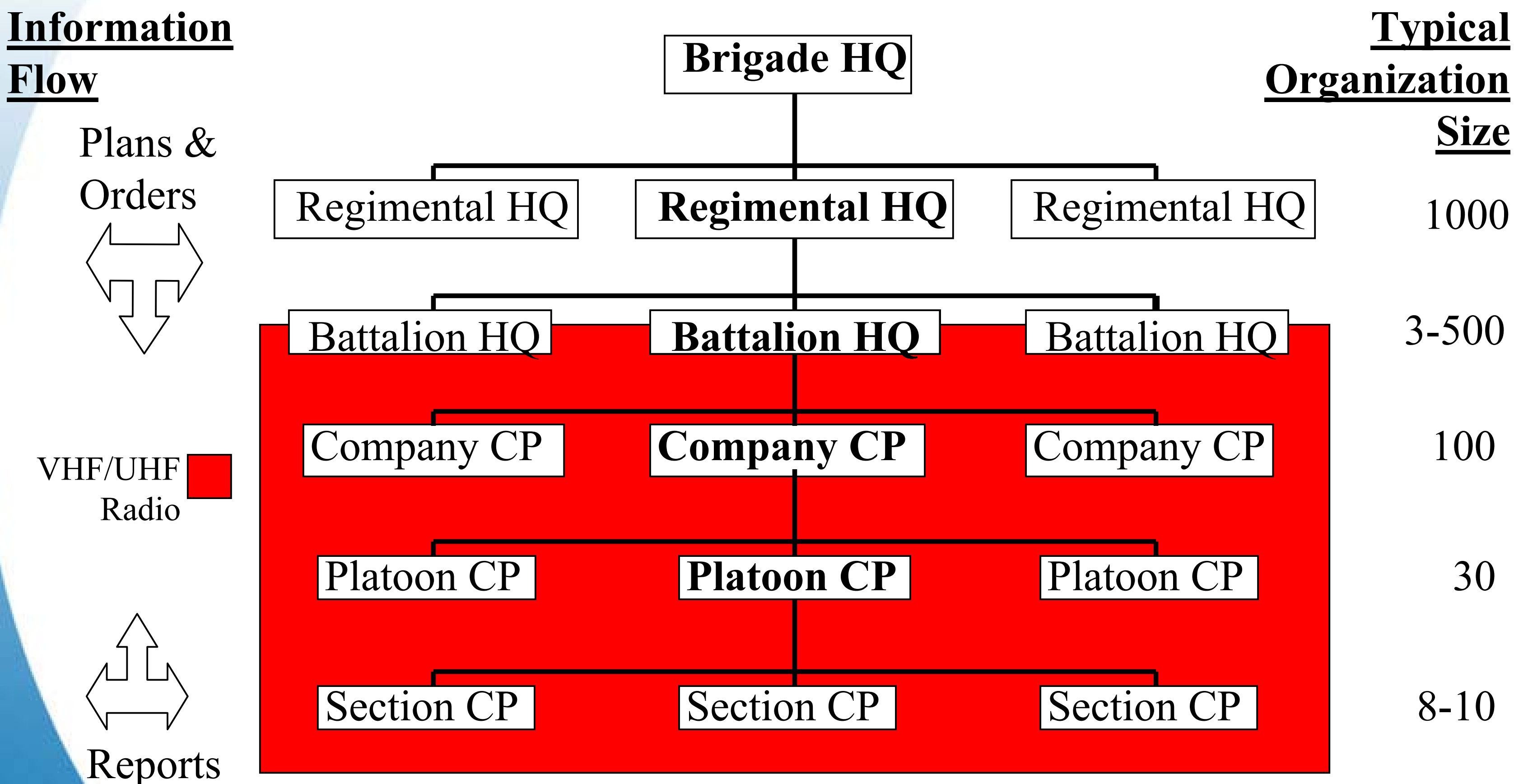
Army Command and Control Structure

Typical Organization Size

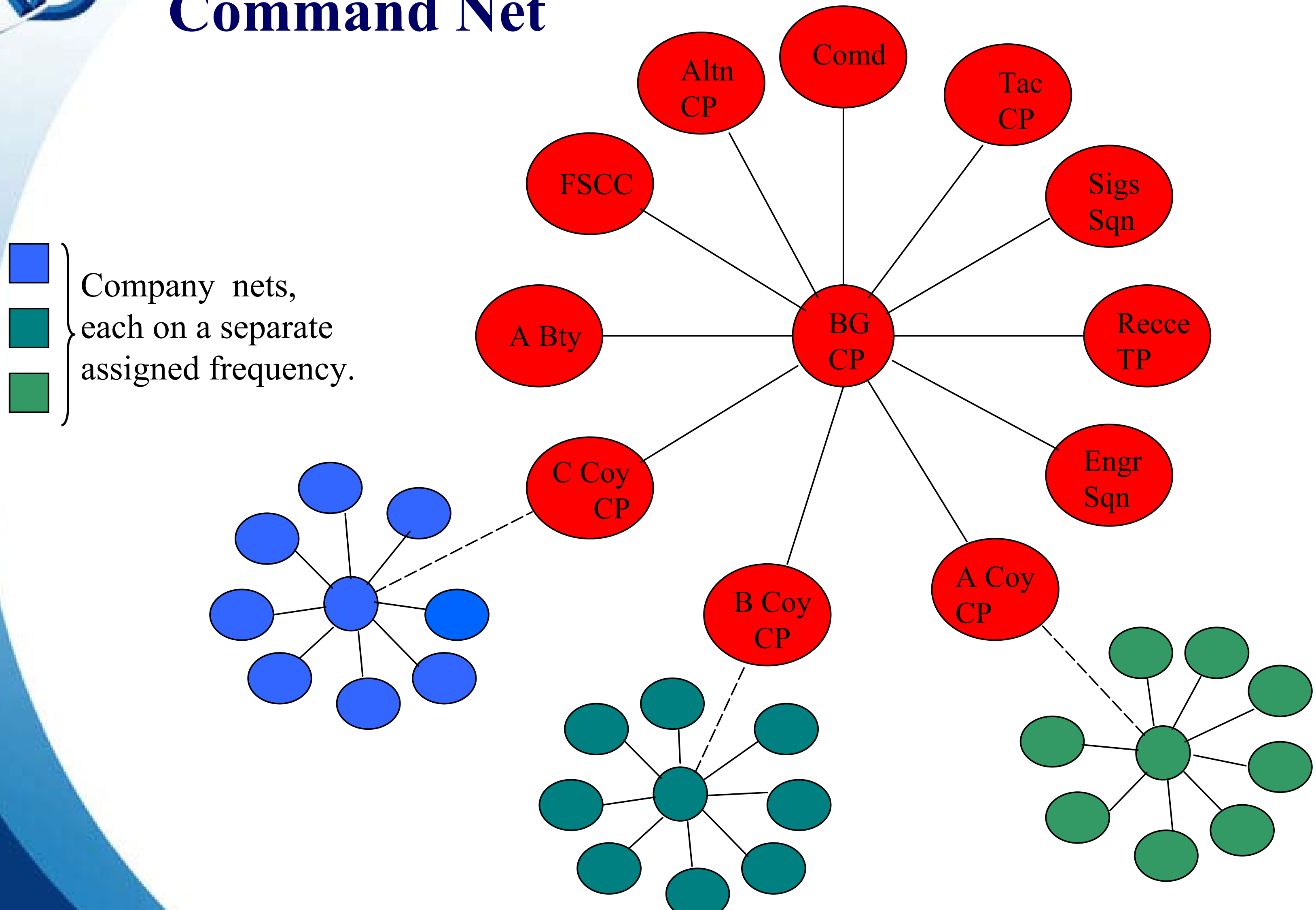


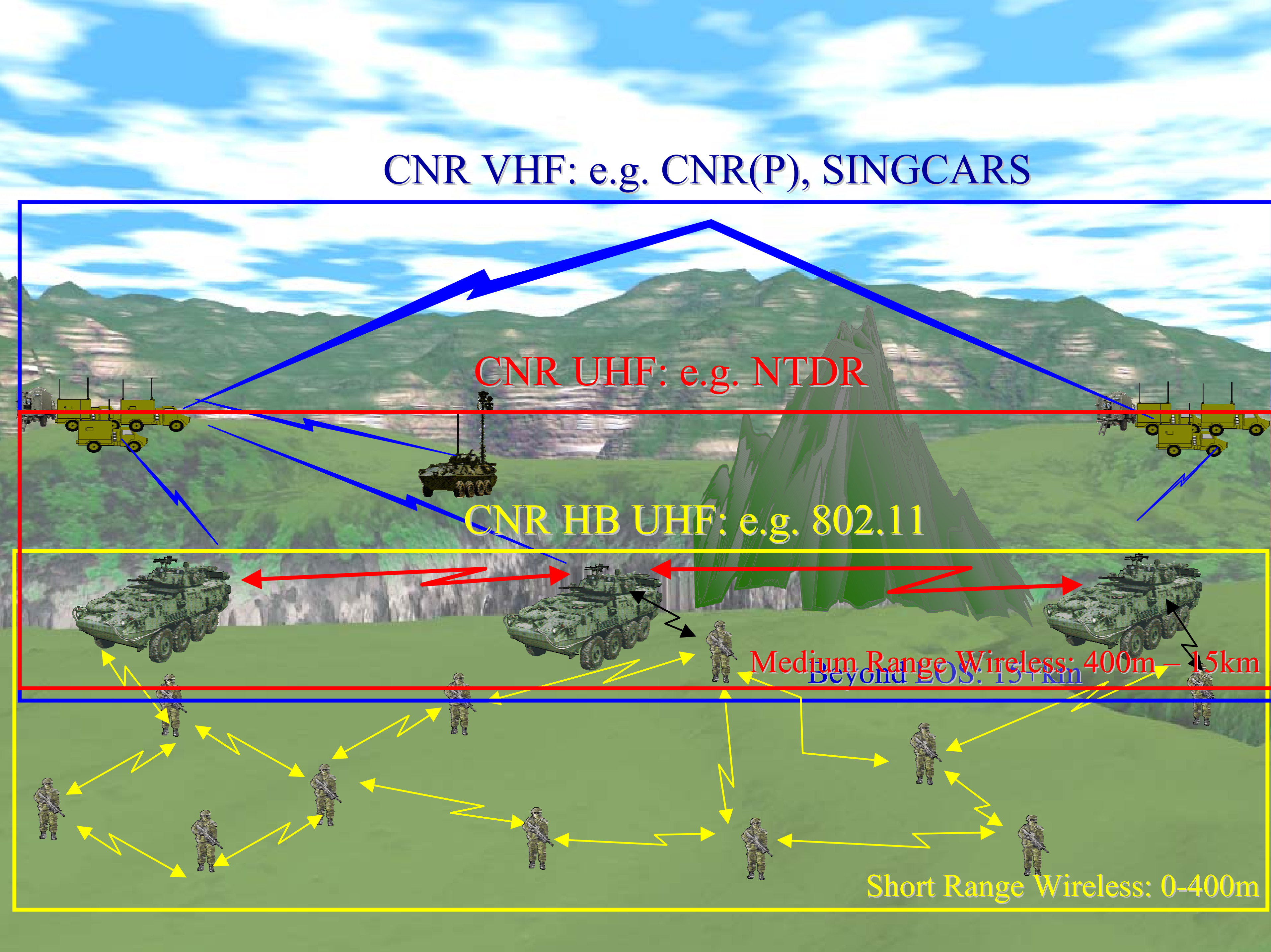
The Tactical Communications Environment

Army C2 Structure -Tactical Domain



Notional Battle Group (augmented Battalion) Command Net




CNR VHF: e.g. CNR(P), SINGCARS
CNR UHF: e.g. NTDR
CNR HB UHF: e.g. 802.11
Medium Range Wireless: 400m – 15km
Beyond LOS: 15+km
Short Range Wireless: 0-400m

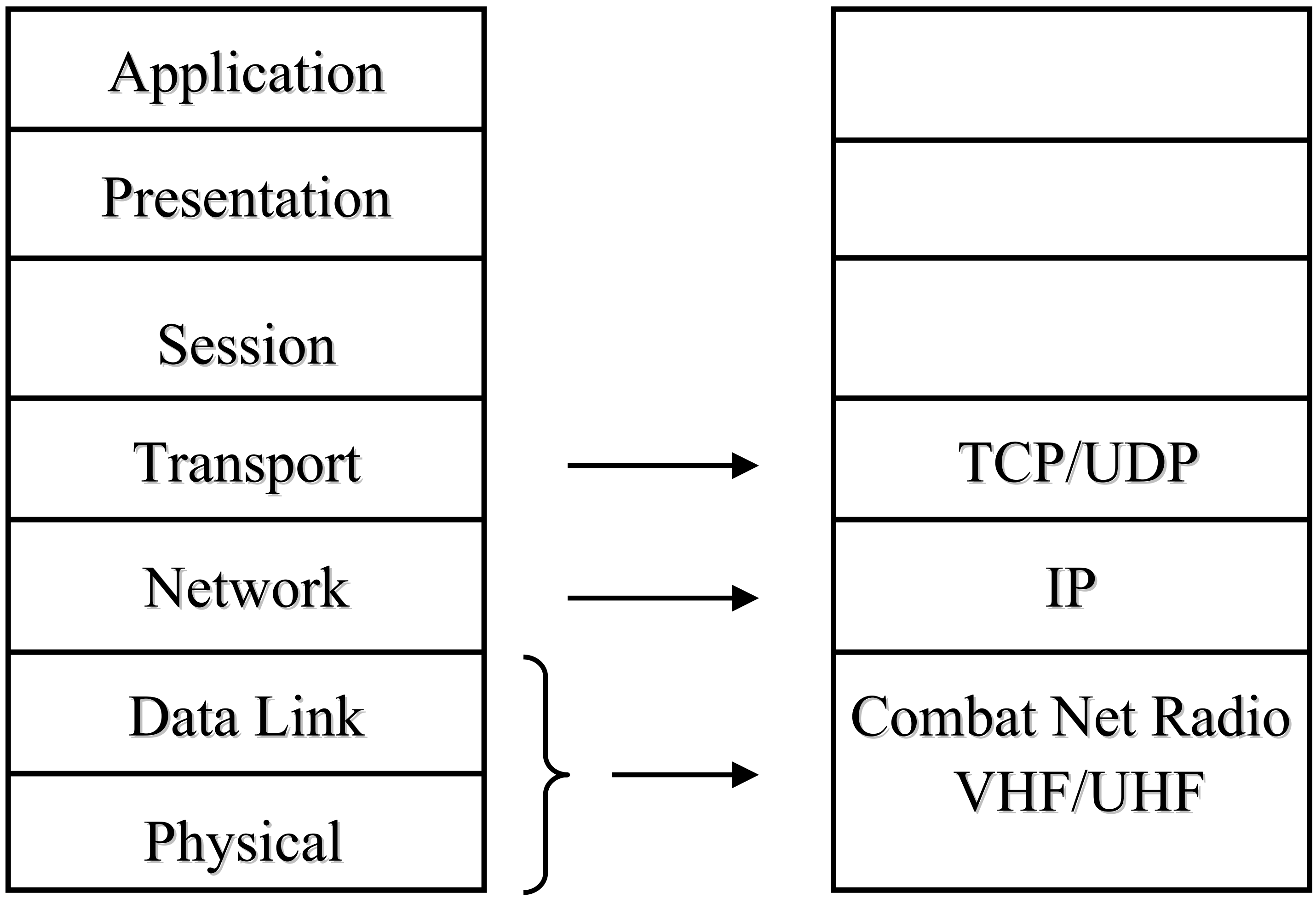
CNR Domain

- VHF: Vast majority of radios capable of 16kbps half duplex.

- UHF: Radios capable of 288kbps full duplex.

- High Band UHF: (e.g. 802.11) capable of 11 Mbps.

Network Layers



CNR – VHF

- Base rate 16 kbps half duplex
- Reality: usable throughput at the application layer is a fraction of the base rate:

  Max throughput on DATA ONLY network can be as low as 1 kbps

  SHARED AMONGST USERS

  → 25 radios/net = 40 bps/user

- Reality: residual BER as high as 10^{-5}

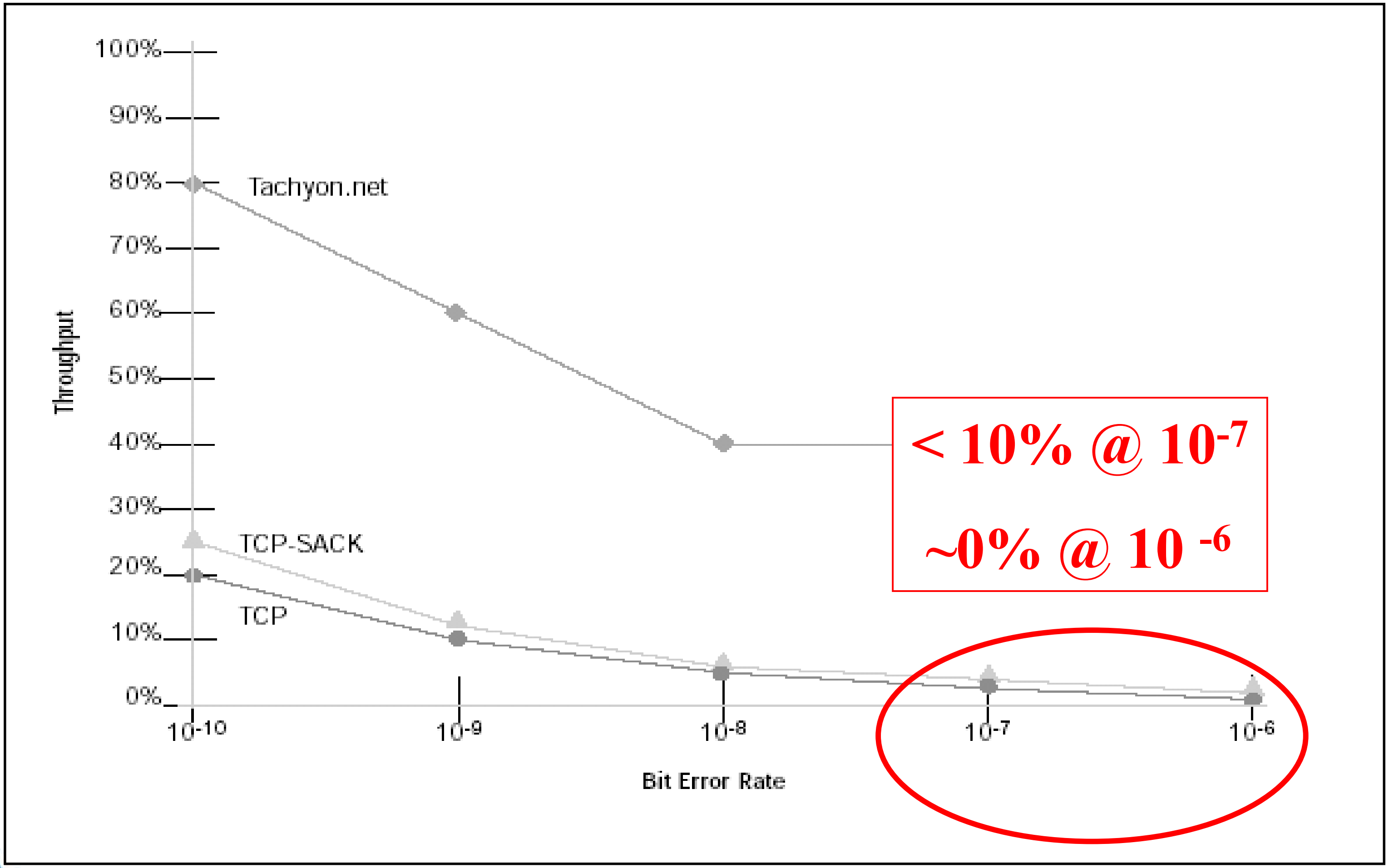
CNR UHF (225 – 450 MHz)

- 288 kbps is for 'well situated' sites
- Reality: true tactical environment performance is approximately:
  - ~16kbps from 22kbps link; and
  - ~80kbps using a 100 kbps link;
- Available throughput is still shared amongst users (80kbps/25 = 3.2 kbps)
- Error conditions similar to VHF

Transfer Control Protocol (TCP)

- TCP was designed for wired networks:
  - controls designed for congestion, not errors
  - TCP is very sensitive to Bit Error Rate (BER) and Latency
- Error in wireless domain triggers TCP congestion controls (e.g. 1 packet lost = 50% cut in tx rate)
- TCP is connection-oriented
  - in wireless tactical domain (high BER, latency, long fades) TCP connections timeout regularly

TCP and Bit Error Rate



Challenges Posed by the Tactical Communications Environment

Network Topology on the Tactical Battlefield

- Unreliable shared medium (radio) provides comms links
- Highly mobile entities participate as nodes on C2 network
- Network of sub-networks; each sub-net on different base frequency
- Nodes frequently connect/disconnect from subnetworks
- A single radio can participate on only one sub-net at a time.
  - participation on multiple nets requires multiple radios
- Number of radios in vehicle restricted by space limitations

Tactical Communications Constraints

- Units are highly mobile
- Communicate by radio (voice and data; voice only; data only)
- Low data throughput (< 1 kbit/second for CNR)
- Variable data throughput
  - highly dependent upon traffic load on communications network
- Unreliable links (frequent disconnection, high bit error rates)

Effective Data Distribution in Tactical Wireless Domain

- Autonomous cooperating nodes (disconnected operation)
- Peer-to-peer and 'all-informed' distribution model
    - profit from shared medium
    - change role without substantial one-time data transfer
    - recover data from any node (avoid single point of failure)
- Propagate only what has changed, asynchronously
- Data recovery must be carefully managed (bandwidth)
- Data ownership important issue (integrity & bandwidth)
- Negative acknowledgement scheme

The challenge – how to communicate and share information effectively in this highly constrained communication environment

Data Replication over Disadvantaged Tactical Communication Links

IST-030/RTG-012 Workshop
DRDC Valcartier, Quebec, CA, 11-12 Sep 02

Workshop Summary

Defence Research and Development Canada
Recherche et développement pour la défense Canada

Canada

What is Data Replication ?

- Systematic propagation and maintenance of copies of data between datastores within a distributed environment

Why Replicate Data in the Tactical Domain ?

- Timely sharing of information enables:
  - shared awareness
  - increased speed of command
  - higher tempo of operations
  - greater lethality
  - increased survivability
- More bandwidth-efficient than structured message exchange
- Interoperability through DB to DB exchange

Synchronous vs Asynchronous Replication

- ***Synchronous*** replication provides 'tight consistency' between data stores through two-phase commit protocol (update to originating and replicate database occurs at same time)
  - requires high network availability and bandwidth
  - not practical in tactical wireless domain
- ***Asynchronous*** replication provides 'loose consistency' between data stores.
  - there is latency before data consistency is achieved because replication occurs some time after originating transaction.
  - used in tactical wireless domain

Desirable Characteristics of Replication Mechanism for Tactical Wireless Domain

- Asynchronous Replication
  - most commercial replication mechanisms support tight consistency, or loose consistency but assume latency not an issue
  - in reality, ‘loose consistency’ often not achievable in tactical wireless domain
  - due to behaviour of tactical comms network, some replicated data may not reach its destination
  - must live with a state of ‘lazy consistency’, in which the datastores never fully synchronize and it is always the case that, at any given time, some data values will be inconsistent.
  - mechanism should protect consistency of high-value information when network performance degrades (graceful degradation)
- Propagate changes only
  - bandwidth-efficient when replicate only values that have changed

Asynchronous Replication

- Communication Types
  - database-to-database (favoured)
    - replication of database transactions
    - high application transparency
    - facilitates interoperability
  - process-to-process
    - publish/subscribe messaging, store & forward distribution
    - not application transparent (requires APIs)
- Data Ownership Model (right to modify value)
  - single ownership (favoured)
  - shared ownership
  - transferable ownership

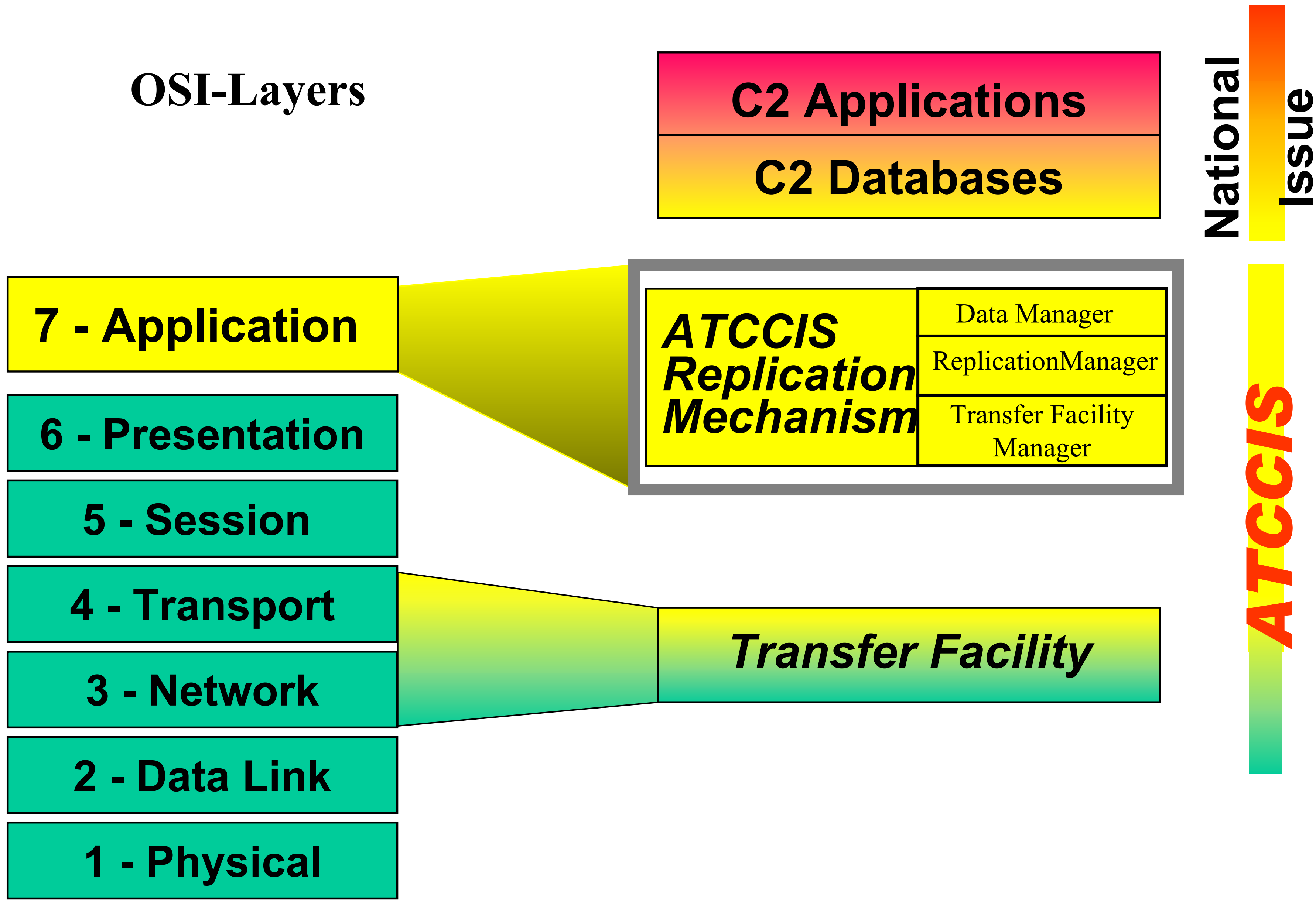
Desirable Characteristics of Replication for Tactical Wireless Domain - Summary

- Peer-to-peer distribution model
- Multicast or broadcast protocol (connectionless)
- Asynchronous replication
  - enforcing ‘lazy consistency’
    - graceful degradation protecting consistency of high-value data
  - database-to-database communication
  - propagate only what has changed
  - single data owner model

Army Tactical Command Control and Information System (ATCCIS) Background

- ATCCIS Objectives
  - 16 NATO nations
  - Interoperability between C2ISs
  - Software/Hardware/Vendor-independent Solution
  - Two Main Products: Common Data Model (LC2IEDM) and ARM (ATCCIS Replication Mechanism) specification
  - Database-to-Database Replication
- MIP (Multilateral Interoperability Programme)
  - Goal: To Field an Interoperability Solution
  - Adopted ATCCIS Products
  - Merged with ATCCIS in 2002

ATCCIS and OSI Layers



ATCCIS Replication

- Replication Contracts
  - agreement by both Parties -> automated exchange
  - “negotiated push”, scheduled replication
- Filters
  - on data value and data source
- Replication Messages
  - incremental update (new/changed data only)
  - bulk update (for synchronization)
  - control messages (e.g. activate node, propose contract)

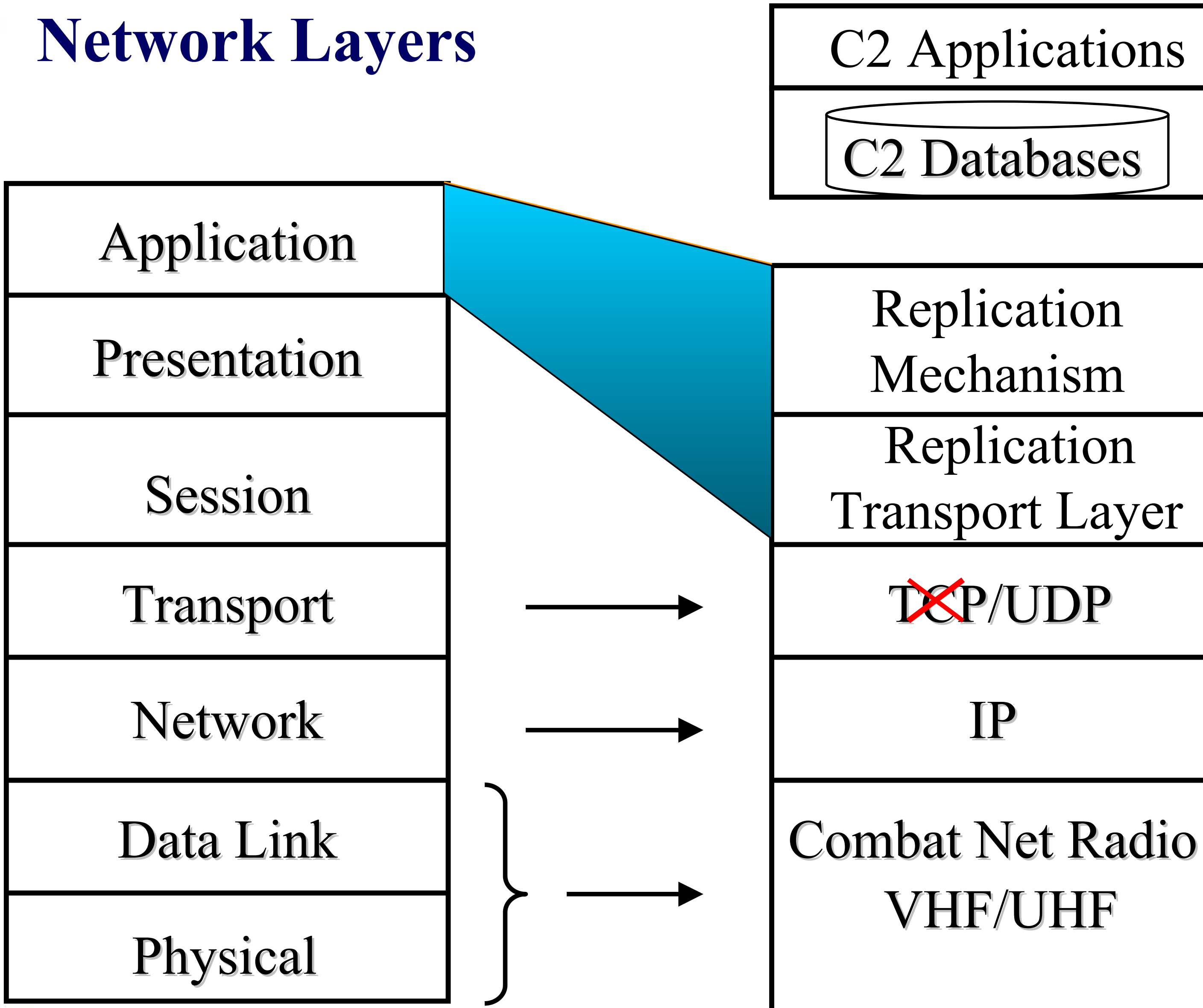
Desirable Characteristics of Replication for Tactical Wireless Domain - Summary

	ARM
• Peer-to-peer distribution model	YES
• Multicast or broadcast protocol (connectionless)	NO
• Asynchronous replication	YES
– enforcing ‘lazy consistency’	NO
• graceful degradation	NO
– database-to-database communication	YES
– propagate only what has changed	YES
– single data owner model	YES

What is Missing ?

- In the tactical wireless domain, for optimum performance the replication protocol must be able to sense, and adapt its behaviour to, the constantly varying state of the communications network
- A Replication Transport Layer must be installed that sits between the Replication Mechanism and the network layers
- The Replication Transport Layer should
  - take advantage of shared medium
  - use a standard connectionless transport protocol (UDP not TCP)
  - sense and adapt to varying state of comms network

Network Layers



Functional Requirements for Replication Mechanism and Replication Transport Layer

- Replication Mechanism (RM) must
  - determine when replication is to occur (context-sensitive)
  - determine what is to be replicated
  - assemble the replication Protocol Data Unit (PDU)
  - apply received PDUs
- Replication Transport Layer (RTL) must support
  - prioritization at PDU level (sensitive to time-varying network state)
  - retransmission protocol (sensitive to time-varying network state)
  - degree of fault tolerance
  - fragmentation/defragmentation of PDUs
  - acknowledgement scheme (negative ACK)

Functional Requirements Delivered by Combination of RM and RTL

- Determine level of effort allocated to PDU Tx
  - based on importance of PDU content
    - number of retransmission attempts
    - choice of class of transport service (guaranteed, best effort)
- Track and enforce data ownership
  - authority structure for management of database keys

Conclusions

- To be effective in the tactical wireless domain, replication mechanism and protocols must be capable of sensing and adapting to the changing state of the communications network (context-awareness)
- Commercial replication mechanisms support ‘tight consistency’, or ‘loose consistency’ but assume latency (time to resynchronize) not an issue
- No replication mechanism developed to date has proven fully effective in the tactical military domain

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Role of Middleware in Systems Functioning over Mobile Wireless Networks

IST-030/RTG-012 Workshop
FGAN/FKIE, Wachtberg, GE, 26-27 Aug 03

Workshop Summary

Defence Research and Development Canada
Recherche et développement pour la défense Canada
Canada

What is Middleware ?

- Middleware - software providing a set of enabling services that resides between applications and the underlying operating systems, network protocol stacks and hardware.
  – can allow multiple processes running on one or more hosts to interact transparently across a network
  – can enable and simplify integration of heterogeneous software and hardware components.

Middleware Requirements for Tactical Mobile Wireless Environment

- In the tactical mobile wireless environment, one is concerned with middleware suppporting peer-to-peer interactions between mobile hosts.
- Different from Internet middleware applications that are intended to enable a wireless device to connect to the Internet for personal or e-business reasons.

Middleware Categories

- Four broad categories of middleware identified
  - transactional
  - message-oriented
  - procedural
  - object and distributed object (component)

Transactional Middleware

- Supports transactions involving components that run on distributed hosts (primarily DB transactions)
  - DB Transaction - a set of DB operations that must succeed or fail as a single unit
- Transaction management MW – preserves transactional integrity through support of rollback, etc
  - using two-phase commit protocol
- Data replication MW – copies DB transactions from source DB to multiple replicate DBs
  - synchronous replication (using two-phase commit)
  - asynchronous replication (more bandwidth-friendly, used in wireless environment)

Message-Oriented Middleware

- Supports communication between distributed system components through message exchange
  - event notification, request for service execution
- Examples
  - Java Message Service, TIBCO Rendezvous
  - publish/subscribe or synchronous message queues
  - event notification systems (e.g. CORBA event notification, Jini)
- Advantage – completely decouples producers and consumers of information (‘truly connectionless’)
- Disadvantage - implemented, in general, using a centralized server with message caching

Procedural MW

- Based on procedure calls, a concept rooted in procedural programming languages
- Remote Procedure Calls –
  - developed by Sun in early 80’s
  - invoke procedure that resides outside of execution context (process) of caller
- Example – X/Open Distributed Computing Environment

Object and Distributed Object (Component) MW

- Objects – software entities that encapsulate both data describing the object and the methods operating on those data
- Distributed objects (components) – standalone entities that can
  - reside anywhere on a network
  - be accessed by remote clients via method invocations
- MW makes OO features available for the development of distributed systems
  - e.g. object identification through references and inheritance
- Examples
  - CORBA, DCOM, Enterprise Java Beans, .NET

Conclusions

- Object-oriented MW has most to offer to tactical wireless domain
  - offers most flexible systems
  - no known current implementation that meets all needs
  - significant communication overhead may inhibit widespread use
- Transactional middleware has important role in tactical wireless domain
  - custom asynchronous replication mechanism (ARM) supporting info exchange through direct DB to DB communication

Traditional Middleware Requirements

- Network communication
  - support marshalling and unmarshalling
  - provide higher level primitives
- Coordination
  - component synchronization, activation, deactivation
- Reliability
  - support fault-tolerance and different levels of QoS
- Scalability
  - load balancing (transparent replication, access, and migration)
- Heterogeneity
  - integrate elements from various execution contexts

Requirements for Next Generation Middleware in Wireless Domain

- Context Awareness
  - detect changes in execution context
  - disclose changes in execution context to application.
- Adaptivity
  - adapt to changes in execution context
  - middleware
  - application
- Lightweight
  - limited range of functionality, low resource requirements (memory, CPU cycles)
  - low bandwidth demands for control/management

Context Awareness

- Middleware should serve as a mediator for collecting, organizing, and disseminating *relevant* context information to the application and transport mechanisms

Context Awareness

- MW should maintain shared perception of network state
  - needs feedback from underlying transport mechanisms
    - e.g. link quality, transmit power, residual energy at nodes
  - each node develops own perception of network state
  - periodically share this perspective across all nodes
- MW should maintain shared perception of own state
  - e.g. replication middleware -> data provider needs to know which nodes are available as data receivers
- Periodically communicate status of network and middleware to user application (and possibly communicate user needs to network)

Adaptivity

- Change behaviour based on changed context
- Middleware
  - choice of protocols
  - retransmission rate and number of attempts
  - adjustment of services offered to application (e.g. reduction of frame rate for real time video streaming application)
- User Application
  - transmission prioritization strategy
    - communications context
    - battlefield context

Conclusions

- Traditional middleware solutions assume that applications in distributed systems run in a static environment

- To be effective in the tactical mobile wireless domain, next-generation middleware must support

  - context-awareness

  - adaptivity

  - lightweight processes (local resources, bandwidth)

Questions ?